

## Description

# Hybrid Electric Vehicle Energy Management System

### BRIEF DESCRIPTION OF DRAWINGS

[0001] In the accompanying drawings:

[0002] *FIG. 1* illustrates a block diagram of a hybrid vehicle system incorporating an energy management system;

[0003] *FIG. 2* illustrates a turbine power generator;

[0004] *FIG. 3* illustrates an internal combustion engine power generator;

[0005] *FIG. 4* illustrates a portion of a map containing various road segments, intersections, destinations and destination circles;

[0006] *FIG. 5* illustrates a data structure that provides for relating location coordinates to associated road lists, destination circle lists and intersection lists;

[0007] *FIG. 6a* illustrates a data structure for a road list that is linked to the data structure of *Fig. 5*;

- [0008] FIG. 6b illustrates a data structure for road property data that is linked to the data structure of Fig. 6a;
- [0009] FIG. 7a illustrates a data structure for a destination circle list that is linked to the data structure of Fig. 5;
- [0010] FIG. 7b illustrates a data structure for destination circle data that is referenced by the data structure of Fig. 7a;
- [0011] FIG. 7c illustrates a data structure listing the destinations that are associated with a particular destination circle, linked to the data structure of Fig. 7b;
- [0012] FIG. 7d illustrates a data structure listing the properties of each destination that is referenced by the data structure of Fig. 7c;
- [0013] FIG. 8a illustrates a data structure for an intersection list that is linked to the data structure of Fig. 5;
- [0014] FIG. 8b illustrates a data structure for intersection data that is referenced by the data structure of Fig. 8a;
- [0015] FIG. 8c illustrates a data structure for a list of roads that intersect at a particular intersection, linked to the data structure of Fig. 8b;
- [0016] FIG. 8d illustrates a data structure for a list of destinations that are reachable from a particular intersection, linked to the data structure of Fig. 8b;
- [0017] FIG. 9 illustrates a data structure of possible next destina-

tions associated with each destination;

[0018] FIG. 10 illustrates a data structure for a particular route associated with a particular driving pattern, linked to the data structure of Fig. 9;

[0019] FIG. 11 illustrates a flow chart of an energy management control process by the energy management system;

[0020] FIG. 12 illustrates a flow chart of a route responsive control process that is invoked by the process of Fig. 11;

[0021] FIG. 13 illustrates a flow chart of a route processing process that is invoked by the process of Fig. 12; and

[0022] FIG. 14 illustrates a flow chart of a predicted route processing process that is invoked by the process of Fig. 13.

## DETAILED DESCRIPTION

[0023] Referring to Fig. 1, an *energy management system 10* is adapted to control a *hybrid vehicle system 12* so as to provide for improving the efficiency of operation thereof responsive to an automatic recognition of an associated driving pattern of the *vehicle 14*.

[0024] The *hybrid vehicle system 12* utilizes a *power generator 16* to generate electrical power which is coupled through an *electrical power controller 18* to either a *traction motor 20* or an *energy storage device 22*. The *electrical power controller 18* also provides for supplying electrical power to the *traction motor*

20 from the *energy storage device 22* as necessary. The *vehicle 14* is propelled by *shaft power 23* from the *traction motor 20* through a *final drive system 24* of the *vehicle 14*, e.g. a differential and associated drive wheels. Alternatively, the *traction motor 20* could be implemented as a plurality of in-wheel or hub *traction motors 20* so that each of the two or four drive wheels is individually powered. As yet another alternative, one *traction motor 20* could be used to power one pair of drive wheels through a differential, and a pair of in-wheel or hub *traction motors 20* could be used to power another associated pair of drive wheels. For example, in one embodiment, the *power generator 16* comprises a *prime mover 16'* comprising a heat engine which generates mechanical power that is coupled to an *electric generator or alternator 26* to generate the *electric power 27*. The *prime mover 16'* could operate in accordance with any of a variety of thermodynamic cycles, for example an Otto cycle, a Diesel cycle, a Sterling cycle, a Brayton cycle, or a Rankine cycle. In another embodiment, the *power generator 16* comprises a *fuel cell 16''* that generates *electric power 27* directly, the output of which may be transformed by a *power converter 26'* into a form that is suitable for use by the *traction motor 20* or *energy storage device 22*. Generally,

the *power generator 16* generates power from sources of *fuel 28* and *air 30* that are combusted or reacted so as to generate energy and an associated stream of *exhaust 32*. The *power generator 16* is controlled by a *power generator controller 34*, which controls the flow of *fuel 28* and *air 30* thereinto, and which may also control an associated *ignition system 36* thereof. Furthermore, in combination with a *power generator 16* comprising a *prime mover 16'*, the *power generator controller 34* is operatively coupled to a *starter control system 38* which in turn provides for controlling the *electrical power controller 18* to direct power from the *energy storage device 22* to the *electric generator or alternator 26* which then runs as a motor to provide for starting the *power generator 16*, in combination with appropriate control of *fuel 28*, *air 30* and the *ignition system 36*. Furthermore, the *power generator controller 34* provides for controlling the *fuel 28*, *air 30* and *ignition system 36* responsive to *measurements 40* of the operating condition (e.g. RPM, temperature, pressure) the *power generator 16* so as to control the power output, operating efficiency, or emissions thereof.

[0025] The *vehicle 14* also incorporates a *vehicle location sensor 42* that cooperates with an associated *map database 44*, and which may cooperate with a *vehicle speed or distance sensor*

, so as to provide for a measure of the location of the *vehicle 14* with respect to a road system upon which the *vehicle 14* may travel. For example, the *vehicle location sensor 42* may comprise a GPS receiver or other navigation system that determines a location of the *vehicle 14* from signals external thereto, or another type of on-board navigation system, e.g. using a differential odometer in combination with a heading from an electronic compass, e.g. a flux-gate compass; or an inertial navigation system. Furthermore, the *vehicle location sensor 42* may provide for a measure of vehicle location relative to any particular origin, for example, one's home, work, or a geographic point of reference, e.g. the North or South Pole, the equator and a meridian, e.g. the Greenwich Meridian. For example, a GPS receiver would typically provide location coordinates in accordance with World Geodetic Survey (WGS). The *vehicle location sensor 42* may also utilize road map data with an associated map matching algorithm to improve the estimate of vehicle location, wherein a location measurement from the *vehicle location sensor 42* is combined with the location of proximate roads, subject to a constraint that the *vehicle 14* is located on a road, so as to provide for an improved estimate of vehicle location.

[0026] The *map database 44* can be generated from existing industry and government sources based upon topographic maps, and would, for example, provide for locations of roads in coordinates of latitude, longitude and elevation, so as to provide for determining the energy requirements of a particular route, particularly previously untraveled routes for which the destination is known. Electronic maps are widely known and used by existing vehicle navigation systems.

[0027] The *energy management system 10* further comprises a *route computer system 48* which receives data from the *vehicle location sensor 42* and the *map database 44*, and which incorporates and/or is operatively coupled to a *memory 50* that records vehicle driving patterns. Responsive to the location of the *vehicle 14*, and the current driving pattern thereof associated with the latest trip, the *route computer system 48* attempts to predict the ultimate destination of the *vehicle 14* by comparing the present driving pattern with previous driving patterns stored in *memory 50*, and if a destination can be predicted, provides for controlling the *hybrid vehicle system 12* in accordance with the energy and other requirements associated with the remainder of the trip. More particularly, the *route computer system 48* pro-

vides for controlling the generation of power with the *power generator 16* and the transfer of power to or from the *energy storage device 22* so as to accomplish a particular objective or set of objectives, such a minimizing fuel consumption subject to reaching the destination or destinations subject to operator control of speed and braking of the *vehicle 14*.

[0028] The *power generator 16*, *energy storage device 22* and *traction motor 20* are controlled by the *power generator controller 34*, the *electrical power controller 18* and a *traction motor controller 52* respectively, responsive to corresponding signals from the *route computer system 48* and the *driver 60.1*. More particularly, responsive to a signal from an accelerator pedal operated by the *driver 60.1*, the *traction motor controller 52* controls the amount of power that is output from the *traction motor 20* to the *vehicle final drive system 24*, and the *power generator 16*, *electrical power controller 18* and *energy storage device 22* are controlled by the *route computer system 48* responsive to power demands from the *traction motor 20* and responsive associated route dependent energy management by the *route computer system 48*. The *power generator controller 34*, *electrical power controller 18* and *traction motor controller 52* can also be adapted to provide information to



the *route computer system 48*. For example, the *electrical power controller 18* would provide information about the amount of energy stored in the *energy storage device 22* which would be used by the *route computer system 48* in determining a particular overall control strategy.

[0029] Electrical power generated by the *electric generator or alternator 26* and not required by the *traction motor 20* to drive the *vehicle 14*, or electrical power generated by the *traction motor 20* from regenerative braking, can be stored in the *energy storage device 22*. For example, when *electric power 27* is required to be generated by the *electric generator or alternator 26*, it is beneficial to operate the associated *power generator 16* at maximum efficiency, which generally corresponds to a relatively high power operating point, so that there may be more power generated by the *electric generator or alternator 26* than might be required by the *final drive system 24* to drive the *vehicle 14*. For example, an internal combustion engine *prime mover 16'* would generally operate at maximum brake specific fuel consumption at wide open throttle for which the associated pumping losses are minimized.

[0030] The *energy storage device 22* may, for example, comprise a *battery 22.1*, an ultra-capacitor, or a flywheel (e.g. a fly-

wheel in cooperation with an associated motor/generator). For a *battery 22.1 energy storage device 22*, the *energy management system 10* provides for enabling a higher state of charge than might otherwise be provided in a conventional hybrid vehicle system, so as to better accommodate vehicle usage patterns. The characteristics of the *battery 22.1*, e.g. charging rate, capacity, number of allowable discharge cycles, cost, etc. would depend upon the particular vehicle design, and could be considered by the *route computer system 48* in determining the overall system control strategy. Generally, a *battery 22.1* having a larger storage capacity enables longer periods of operation using stored energy without requiring activation of the *power generator 16*, which provides for improved system performance. The *energy storage device 22* can be charged from a *stationary electrical power source 54*, e.g. when the *vehicle 14* is parked, by plugging into a stationary power supply coupled to the power grid, as an alternative to charging with the *power generator 16* during operation of the *vehicle 14*. This provides for reductions in fuel consumption and emissions generated by the *power generator 16*, and may reduce associated overall operating costs if the cost of *electric power 27* from the *stationary electrical power source 54* is less than the

cost to generate an equivalent amount of useable *electric power 27* using the *power generator 16*.

[0031] The *energy management system 10* may further comprise one or more *environment sensors 56*, for example, a pressure sensor or temperature sensor, so as to provide for environmental information that may be influence the overall control strategy. For example, the ambient temperature can influence the storage characteristics of a *battery 22.1 energy storage device 22*, or the altitude -- sensed from ambient pressure -- can influence the operating characteristics of an internal combustion engine or turbine *prime mover 16'*. Furthermore, *environment sensors 56* can be provided to sense dynamic pressure at the front of the *vehicle 14* so as to provide for determining a measure of wind speed, which can then be used by the *route computer system 48* as a factor in determining the energy required to reach a particular designation.

[0032] Furthermore, the *energy management system 10* may utilize information from an external *road or environment information system 58*, such as an external traffic control information system that might provide information about traffic delays or road closures that could be used by the *route computer system 48* to select an alternate route to be used in deter-

mining the predicted driving pattern for calculating the overall control strategy. Furthermore, the *road or environment information system 58* can provide weather information such as wind or precipitation conditions that can be used by the *route computer system 48* as a factor in determining the energy required to reach a particular designation.

[0033] The *operator 60*, e.g. *driver 60.1*, interfaces through an *operator interface 62* with the *route computer system 48* so as to provide inputs, such as "throttle" and "braking" commands, e.g. with conventional throttle and brake pedals of the *vehicle 14*, or inputs through one or more switches, touch pads, a keyboard or touch screen. The *operator interface 62* is also adapted to generate either aural or visual information, e.g. via the instrument panel. For example, upon recognizing a particular driving pattern, the *route computer system 48* could indicate the predicted destination to the *operator 60*, who could then provide a confirmation or not via a spoken command or by pressing a switch. As another example, the *operator 60* could provide a spoken command indicating an intended destination, which would then be used by the *route computer system 48* as the most likely destination to be used for calculating the overall control strategy. Typical drive times, distances, energy

use, etc. can be provided as information to the *operator 60*, and the *operator 60* can communicate with the *route computer system 48* to indicate or confirm intentions so as to improve the overall energy efficiency of the *vehicle 14*.

[0034] While the *energy management system 10* can automatically operate without explicit input from the *operator 60*, the *operator interface 62* can be adapted to provide for inputs from the *operator 60* that would otherwise need to be automatically learned by the *route computer system 48*, or to provide for other inputs to enable the *operator 60* to better optimize fuel efficiency or overall economy. For example, destinations could be preprogrammed by the *operator 60*, or set or recorded by the operator upon arriving at the particular destination. Otherwise, the *route computer system 48* would automatically record a particular destination location after a given number of occurrences of reaching that particular destination, wherein the given number could be set by the *operator 60*. Furthermore, the *operator 60* could initiate the recording of driving pattern data over a particular trip and stop recording when the associated destination is reached, so as to establish baseline data for determining energy usage. This may be particularly beneficial for routine trips, such as travel between home and

work, where a particular route is used repetitively. However, typically the *energy management system 10* would operate automatically without the *operator 60* having to communicate an intended destination or driving route to the *route computer system 48*, but predicting the likely destination of the *vehicle 14* based upon probability and correlation with past driving patterns and considering other information such as the time of day, day of week, date, number of occupants, etc.

[0035] Furthermore, in combination with the use of a *stationary electrical power source 54* to charge the *energy storage device 22*, price of the power from the *stationary electrical power source 54* could either be input to the *route computer system 48* by the *operator 60* using the *operator interface 62*, e.g. a keypad, or could be automatically communicated to the *route computer system 48* as information modulated on the incoming *electric power 27*. Accordingly, the *route computer system 48* could then advise the *operator 60* of the threshold price of *fuel 28* above which it would be more economical to use *electric power 27* from the *stationary electrical power source 54* when possible.

[0036] The *energy management system 10* can be adapted to operate with various hybrid vehicle architectures. For example, the

*energy management system 10* is well suited to a series hybrid electric vehicle (HEV) architecture described heretofore, wherein all of the tractive effort to propel the *vehicle 14* is from *shaft power 23.1* produced by the *traction motor 20*, which is powered by either the *power generator 16*, the *energy storage device 22*, or both the *power generator 16* and the *energy storage device 22* simultaneously. Alternatively, the *energy management system 10* can be adapted to operate with a parallel HEV architecture, wherein the tractive effort to propel the *vehicle 14* is provided by a combination of *shaft power 23.1* produced by the *traction motor 20*, and *shaft power 23.2* produced by the *power generator 16* and coupled to the *final drive system 24*, for example, with a *traction motor 20*, or a pair of *traction motors 20*, driving the front wheels of the *vehicle, 14*, and an internal combustion engine, e.g. a Diesel engine, *power generator 16* driving the rear wheels through a differential. The *energy management system 10* can also be adapted to operate with other HEV architectures, such as charge sustaining or charge depleting architectures, or HEV systems incorporating power split drive trains.

[0037] Referring to *Fig. 2*, a *hybrid vehicle system 12.1* is illustrated incorporating a *recuperated turbine engine 64* as the *power*

*generator 16.1. Air 30 compressed by a compressor 66 flows through a first flow path 68.1 of a recuperator 68, which heats the compressed air flow using heat 70 extracted from exhaust 32 flowing through a second flow path 68.2 of the recuperator 68. The first 68.1 and second 68.2 flow paths of the recuperator 68 are adapted to exchange heat therebetween but are otherwise isolated from one another. The heated compressed air 30.2 flows into a combustion chamber 72 where it is mixed with fuel 28 injected therein responsive to a fuel controller 74, and combusted to generate a relatively high temperature exhaust 32.1, which is used to drive a turbine 76, which generates the shaft power 23 used to drive the compressor 66. The turbine 76 also drives the electric generator or alternator 26 operatively coupled thereto, either directly as illustrated, or through a gear reduction assembly. For example, in one embodiment, a four pole electric alternator 26.1 is driven directly by the turbine 76 at a speeds in excess of 120,000 RPM. The recuperator 68 transfers heat 70 from the relatively high temperature exhaust 32.1 out of the turbine 76, to the compressed air 30.1 out of the compressor 66. An ignition system 36.1 operatively associated with the combustion chamber 72 is used to initiate combustion therein. The fuel controller 74 and ignition system 36.1 are operatively*



coupled to the *power generator controller 34* and are controlled responsive to signals therefrom. Generally, the *power generator controller 34* would also monitor and use signals from the *recuperated turbine engine 64*, such as output shaft speed, inlet air temperature, compressed air temperature and/or exhaust temperature in determining the appropriate associated control signal for the fuel controller, either directly, or responsive to a signal from the associated *route computer system 48*. For example, the performance of a turbine engine generally improves as the temperature of the ambient air is reduced, so that a measure of ambient air temperature can be used to optimize the use and operation of the *recuperated turbine engine 64* in the *hybrid vehicle system 12.1*.

[0038] The *recuperator 68* can store a substantial amount of heat energy during the operation of the *recuperated turbine engine 64*, at least a portion of which can be recovered by shutting off or reducing the flow of *fuel 28* prior to reaching a destination, whereby the heat energy stored in the *recuperator 68* heats the *compressed air 30.1* sufficiently to provide for continued extraction of power from the *turbine 76*. This power -- which requires no fuel usage to generate, and which would otherwise be lost -- can be used to

either store energy in the *battery 22.1*, or to drive the *traction motor 20*. A *recuperated turbine engine 64* can generate energy more efficiently by reducing fuel flow while regulating power output to more efficiently recover latent heat energy from the *recuperator 68*. For example, an operating *recuperated turbine engine 64* might provide 32 percent thermal efficiency at constant output, whereas latent heat recovery can provide for 34 to 35 percent thermal efficiency under conditions of reduced fuel flow and reduced power output in advance of an engine idle condition. Accordingly, if the *route computer system 48* is able to predict a destination of the vehicle and determine its location relative thereto, the flow of *fuel 28* to the *recuperated turbine engine 64* can be shut off, reduced, or tapered down sufficiently far in advance of reaching the destination so as to provide for recovering the heat energy from the *recuperator 68* as electrical energy that is either stored in the *battery 22.1* or used to drive the *vehicle 14*. Furthermore, the residual heat energy stored in the *recuperator 68* provides for temporarily shutting off *fuel 28*, e.g. for periods of 10-60 seconds when the *power generator 16* is not needed, and then restarting the *recuperated turbine engine 64* by simply resuming *fuel 28* flow thereto, without requiring restart by

the *starter control system 38*, whereby the *heated compressed air 30.2* out of the *recuperator 68* provides sufficient energy to continue to run the *recuperated turbine engine 64* for a period of time even with the *fuel 28* shutoff.

[0039] Referring to *Fig. 3*, a *hybrid vehicle system 12.2* is illustrated incorporating an *internal combustion engine 78* as the *power generator 16.2*, wherein the *electric generator or alternator 26* would typically be driven through an associated *gear train 80* adapted so that the *electric generator or alternator 26* rotates faster than the *internal combustion engine 78*, so as to provide for a relatively smaller *electric generator or alternator 26* than would otherwise be required. *Air 30* is drawn through an *inlet manifold 82* into a *combustion chamber 84* responsive to the motion of an associated *engine mechanism 86* (e.g. pistons, connecting rods, crankshaft, camshaft and valve train assembly. The flow of *air 30* is controlled by a throttle assembly, the positions of which may be controlled by a *throttle controller 88* responsive to a signal from the associated *power generator controller 34*. Alternatively, the throttle assembly could be eliminated in systems for which the *internal combustion engine 80*, when operated, is always run under wide open throttle (WOT) conditions so as to minimize associated engine pumping

losses. In a naturally aspirated engine, the *air 30* is pumped strictly responsive to the action of the *engine mechanism 86*. Alternatively, the *internal combustion engine 80* could incorporate either a supercharger or a turbocharger to provide for supplemental pumping effort. The *air 30* is combined with *fuel 28* injected into the *inlet manifold 82* under control of a *fuel controller 90* responsive to a signal from the *power generator controller 34*. The *air 30* and *fuel 28* are combusted in the *combustion chamber 84* responsive to repetitive ignition by either a *spark ignition system 36.2* for operation in accordance with an Otto cycle, or by compression for operation in accordance with a Diesel cycle. A portion of the resulting *exhaust 32* may be fed back into the *inlet manifold 82* through an *exhaust gas recirculation (EGR) valve 92*. Generally, the *power generator controller 34* would also monitor and use signals from the *internal combustion engine 80*, such as crankshaft speed (engine RPM), inlet air temperature and/or inlet air flow in determining the appropriate associated control signal for the fuel controller, either directly, or responsive to a signal from the associated *route computer system 48*. Generally, the fuel, spark advance and exhaust gas recirculation may be used as control signals to control the operation of the *internal combus-*

*tion engine 80*, for example, with the objective of minimizing fuel consumption subject to constraints on the amount of associated emissions that are generated in the *exhaust 32*.

[0040] Generally, the *hybrid vehicle system 12* provides for operation with reduced fuel consumption and improved emissions by providing for operating the *power generator 16* in a mode that can be selected to optimize fuel consumption subject to constraints on emissions, independent of the particular driving cycle under which the *vehicle 14* is operated. A difference between the power actually generated by the *power generator 16* and the amount of power required to actually drive the *vehicle 14* can then be accommodated by the associated *energy storage device 22*. For example, if the *power generator 16* were an *internal combustion engine 80* that is operated most efficiently at wide open throttle, then, under driving conditions for which the power output level of the *power generator 16* was greater than that necessary to drive the *vehicle 14*, either the excess power from the *power generator 16* can be stored in the *energy storage device 22*, or, if there was sufficient stored energy in the *energy storage device 22*, the *vehicle 14* could be operated strictly on energy from the *energy storage device 22* without operating the

*power generator 16*. Under driving conditions requiring more power than can be generated by the *power generator 16*, the *vehicle 14* can be operated from energy stored in the *energy storage device 22*, and if necessary, power generated by the *power generator 16*. Accordingly, the control of the *hybrid vehicle system 12* involves determining whether or not, and if so, under what conditions, to run the *power generator 16*, whether to store energy in the *energy storage device 22* or to utilize energy therefrom, and, particularly for a *battery 22.1*, determining the target state of charge of the *energy storage device 22*. The nature of the particular control strategy depends upon a variety of factors. For example, for relatively short trips that can be accomplished strictly with stored energy from the *energy storage device 22*, it may be beneficial to operate entirely on stored energy, without operating the *power generator 16*. The optimal state of charge of the *battery 22.1* at one destination may depend upon what the next destination is likely to be. For example, if the cost of power from a *stationary electrical power source 54* is less than the cost to generate an equivalent amount of power using the *power generator 16*, and if a round-trip between first and second destinations can be accomplished using stored energy from the *energy storage*

*device 22*, then the *vehicle 14* might best be operated without activating the *power generator 16*, notwithstanding that the state of charge of the *battery 22.1* upon reaching the second destination might be lower than what might otherwise be desirable if the *vehicle 14* were operated under some other condition. Furthermore, for a *hybrid vehicle system 12.1* incorporating a *recuperated turbine engine 64*, then under driving conditions for which the *recuperated turbine engine 64* is operated, it is beneficial to be able to control the *recuperated turbine engine 64* prior to reaching a destination so that the heat energy stored in the *recuperator 68* can be extracted. Accordingly, the operation of a *hybrid vehicle system 12* can be improved if it is possible to predict the particular driving pattern of the vehicle.

[0041] This is possible using the *energy management system 10* generally illustrated in *Fig. 1*, which provides for 1) monitoring the location of the *vehicle 14* using a *vehicle location sensor 42* and associated *map database 44*, 2) determining if a particular driving pattern of the *vehicle 14* matches a stored driving pattern so that the destination can be predicted, and 3) if the destination can be predicted, predicting the energy or power requirements of associated with the particular driving pattern, and determining the associated con-

trol strategy for the *power generator 16*, *electrical power controller 18*, *traction motor 20* and *energy storage device 22* responsive to the particular driving pattern.

[0042] Referring to *Fig. 4*, there is shown a portion of a *map 100* which is used to illustrate various aspects and terminology associated with the operations of monitoring the location of the *vehicle 14*, storing associated driving patterns of the *vehicle 14*, and determining whether a particular driving pattern of the *vehicle 14* corresponds to a stored driving pattern. Overlaid on the *map 100* is a grid of *longitude 102: i* and *latitude 104: j* coordinates which define an array of *location cells 106, (i,j)*. The *map 100* contains a plurality of *roads 108: 108.1, 108.2, 108.3* which intersect with one another at a plurality of *intersections 110: 110.1, 110.2, 110.3* at associated *nodes 106* of the associated intersecting *roads (108.1, 108.3), (108.1, 108.2), (108.2, 108.3)* The *roads 108: 108.1, 108.2, 108.3* are stored in memory as a discretized representation comprising a plurality of *nodes 112*, wherein the location of the *road 108* at any point between adjacent *nodes 112* can be found by interpolating therebetween, for example, by linear, quadratic or cubic interpolation, or some other interpolation method. A plurality of *destinations 114: A, B, C, D* are illustrated, which represent locations



that satisfy a predetermined destination criteria, for example locations that the *vehicle 14* had either stopped at a sufficient number of times during its past operation, or locations that were explicitly selected or entered into the *route computer system 48* by the *operator 60*. In *Fig. 4*, two of the *destinations 114: B, D* are illustrated as being coincident with corresponding *nodes 112* of the associated proximate *roads 108: 108.3, 108.1*, and two of the *destinations 114: A, C* are illustrated as being located between *nodes 112* along the associated proximate *roads 108: 108.1, 108.2*. Destinations that are sufficiently proximate to one another are grouped together into what is referred to as a *destination circle 116*, wherein the size of a *destination circle 116* is adapted so that energy required for the vehicle transit the *destination circle 116* is less than a threshold, and the location associated with a given *destination circle 116* would be, for example, that of a location closest to the center of the *destination circle 116* along a proximate *road 108*. Accordingly, the *destination circle 116* provides for reducing the number of locations and the associated computational burden required to predict a particular driving pattern of the *vehicle 14* in order for the *energy management system 10* to benefit from control of the *hybrid vehicle system 12* re-

sponsive to the prediction of the driving pattern and associated energy requirements, without substantially affecting the associated energy calculations used to automatically implement a predestination shutdown of the *power generator 116*. In *Fig. 4*, there are three *destination circles 116*: *116.1*, *116.2*, *116.3* illustrated, wherein the *first destination circle 116.1* includes *destinations A and D*, and the *second 116.2* and *third 116.3 destination circles* include *destinations B and C* respectively. For example, *destination circles 116* would be relatively closely grouped *destinations 114* that are within a given distance of one another, e.g. about a half mile, or a *destination circle 116* that is about 1,500 feet from the associated mean destination. For example, a shopping center with different stores in relatively close proximity would be represented as a *destination circle 116*, the location of which would be used to represent that of each of the particular *destinations 114*, e.g. stores, contained therein. Different *destinations 114* or sets of *destinations 114* could have different associated location error tolerances represented by the radius of the associated *destination circle 116*. For example, principal *destinations 114* such as "home" could have a location error tolerance of about 200 feet. The *route computer system 48* would automatically cluster

proximate *destinations 114* into a corresponding, single *destination circle 116*.

[0043] The *map database 44* may further comprise topographic information such as the *elevation 118* associated with each of the *nodes 112* on the *roads 108*, from which the associated potential energy difference can be calculated for different locations along *roads 108* in the *map 100*.

[0044] In *Fig. 4*, the *vehicle 14* is illustrated as having departed from a *first destination 114.1: A*, and currently traveling along a *first road 108.1* in a Northeast direction approaching a *second intersection 110.2*, on a route that continues on the *first road 108.1* until turning right at a *first intersection 110.1* onto a *third road 108.3* until reaching a *second destination 114.2: B*, wherein the route being traveled is shown with a wider linewidth than are the other segments of the *roads 108*. The *destinations 114* and associated *destination circles 116* illustrated in *Fig. 4*, and the associated information about the associated driving patterns, are stored in the *memory 50* associated with the *route computer system 48*. For example, at the present location of the *vehicle 14* illustrated in *Fig. 4*, the *route computer system 48* would be able to look ahead along the *first road 108.1* to find *intersection 110.2*, for which *destinations B* and *C* would be indicated as possible

destinations that are reachable therefrom, so that the *route computer system 48* would be able to predict that the maximum amount of energy required to reach a destination would be that associated with either *destination B* or *destination C*, whichever is larger. Furthermore, if at the particular date and/or time, *destination B* were more likely than *destination C*, then the *route computer system 48* could determine that *destination B* was the more likely of the two destinations *B, C*. Upon passing through the second intersection *110.2*, the *route computer system 48* would be able to look ahead along the first road *108.1* to find the first intersection *110.1*, for which the only destination reachable would be *destination B*, so that *destination B* would be indicated as the most likely destination *114*. Given a most likely destination *114*, the *route computer system 48* can then determine the distance and energy required to reach the destination *114*, either from past stored measurements or associated mean values, or by calculation from the associated mapping data, including changes in potential energy due to topographic elevation *118* changes between the current location and the likely destination *B*.

[0045] Referring to *Figs. 5* through *10*, there is illustrated an example of a group of data structures which would be

stored in the *memory 50* and *map database 44* of the *route computer system 48* that can provide for storing and predicting vehicle driving patterns and associated energy requirements of the *vehicle 14*.

[0046] Given a measure of location, i.e. *latitude 104* and *longitude 102*, of the *vehicle 14* at a particular point in time, the *data structure 120* illustrated in *Fig. 5* provides for determining the *roads 108*, destination *circles 116* and *intersections 110* within the *location cell 106* of the *map 100* within which the *vehicle 14* is located. The *data structure 120* comprises a plurality of *records 122*, wherein each *record 122* contains a value for each of a plurality of fields identified by the headings in the top line of the *data structure 120*, i.e. *Latitude*, *Longitude*, etc. More particularly, each *record 122* of the *data structure 120* corresponds to the particular *location cell 106* of the *map 100* having a southeast corner corresponding to the values of latitude and longitude from the associated fields of the *data structure 120*, wherein the *location cells 106* cover a given range of longitudes and latitudes. Accordingly, the *records 122* correspond to corresponding longitude and latitude coordinates  $(i,j)$  of the southeast corners of the *location cells 106*, e.g. as illustrated in *Fig. 4*. The *route computer system 48* uses measures of latitude and

longitude from the *vehicle location sensor 42* to determine the particular *record 122* of the *data structure 120* associated with the location of the *vehicle 14*. Then, corresponding values for the fields *RoadList\_ptr*, *DestinationCircleList\_ptr* and *IntersectionList\_ptr* for that particular *record 122* -- indexed as  $(i,j)$  -- are then used to determine the associated *road(s) 108*, *destination circle(s) 116*, and *intersection(s) 110* that may be located within the *location cell 106* of the *map 100* in which the *vehicle 14* is located.

[0047] The value  $RoadList\_ptr(i,j)$  of the *RoadList\_ptr* field of the *record 122* of the *data structure 120* associated with the location of the *vehicle 14* is a pointer to a *linked list data structure 124* illustrated in *Fig. 6a*, wherein each of  $R(i,j)$  records of the *linked list data structure 124* has values for the fields *Road\_ptr*, *nodeID\_min*, and *nodeID\_max*. *Road\_ptr* is a pointer to a *linked list data structure 126* illustrated in *Fig. 6b* of properties for a particular road in the *map database 44*, and *nodeID\_min* and *nodeID\_max* are the minimum and maximum values of the index *Node\_ID* of the portion of the *road 108* identified by the pointer  $Road\_ptr(k)$ , wherein  $k$  can range between *nodeID\_min* and *nodeID\_max* within the *location cell 106* of the *map 100* in which the *vehicle 14* is located. Each record of the *linked list data structure 126* of road prop-

erties contains values of latitude, longitude, elevation, and distance to the previous and next *node 112*, for each *node 112* of the particular road pointed to by the pointer *Road\_ptr(k)*. If a particular *node 112* is also associated with an *intersection 110* or a *destination circle 116*, then values of the associated index of the *intersection 110* or *destination circle 116* are also stored in the associated record of the *linked list data structure 126*, wherein the respective indices are associated with the respective data structures illustrated in *Figs. 8b* and *7b* respectively.

[0048] The value *DestinationCircleList\_ptr(i,j)* of the *DestinationCircleList\_ptr* field of the *record 122* of the *data structure 120* associated with the location of the *vehicle 14* is a pointer to a *linked list data structure 128* illustrated in *Fig. 7a*, wherein each record of the *linked list data structure 128* has a value for the field *DestinationCircleList\_ID*, which is an index to a particular record of a *data structure 130* illustrated in *Fig. 7b* containing information about each *destination circle 116*, including the latitude, longitude and elevation of the center of the *destination circle 116*; and a pointer *DestinationCircle\_ptr* to a *linked list data structure 132* illustrated in *Fig. 7c* containing a list of indexes *Destination\_ID*, each of which identifies a *destination 114* that is part of a particular *destination circle*

116. Each record of the *linked list data structure 132* is an index to a *data structure 134* illustrated in *Fig. 7d* of properties for each of the destinations, each of which is designated by an associated index *Destination\_ID*, including the latitude, longitude and elevation of the destination; a text or audio/visual message used to identify the *destination 114* to the *operator 60*; the index *Intersection\_ID* associated with the data structure illustrated in *Fig. 8b* identifying a proximate *intersection 110* if there is an *intersection 110* proximate to the *destination 114*; the index *DestinationCircle\_ID* of the *destination circle 116* of which the particular *destination 114* is a part with of the *data structure 130* of *Fig. 7b*; and the pointer *RoadID\_ptr* and the index *nearest\_node\_ID* of the *linked list data structure 126* of *Fig. 6b*, which identify the nearest *node 112* on the *road 108* on which the *destination 114* is located.

[0049] The value *IntersectionList\_ptr(i,j)* of the *IntersectionList\_ptr* field of the *record 122* of the *data structure 120* associated with the location of the *vehicle 14* is a pointer to a *linked list data structure 136* illustrated in *Fig. 8a*, wherein each record of the *linked list data structure 136* has a value for the field *Intersection\_ID*, which is an index to a particular record of a *data structure 138* illustrated in *Fig. 8b* containing information about each *intersection 110*, including the latitude, lon-



gitude and elevation of the *intersection 110*; a pointer *IntersectionRoadList\_ptr* to a *linked list data structure 140* illustrated in *Fig. 8c*; and a pointer *DestinationReachableList\_ptr* to a *linked list data structure 142* illustrated in *Fig. 8d*. The *linked list data structure 140* of *Fig. 8c* contains a list of pointers *RoadID\_ptr* to the records of the *linked list data structure 126* of *Fig. 6b*, each record corresponding to a particular *road 108* that intersects at the *intersection 110*; and a value *node\_ID* of the *node 122* of the *road 108* at the *intersection 110*. The *linked list data structure 140* also contains pointers *DestinationReachableList\_1\_ptr* and *DestinationReachableList\_2\_ptr* to *linked list data structures 142* illustrated in *Fig. 8d*, which contain lists of *destinations 114* and *destination circles 116* that are reachable from the particular *intersection 110* along the particular *road 108* in directions of decreasing *node\_ID* and increasing *node\_ID* respectively. The *linked list data structure 142* of *Fig. 8d* contains a list of values of indexes *Destination\_ID* and *DestinationCircle\_ID* which designate *destinations 114* and associated *destination circles 116* that are reachable from the particular *intersection 110*, and which refer to corresponding *data structures 134, 130* illustrated in *Figs. 7d* and *7b* respectively.

[0050] Upon traveling on a particular route in accordance with a

particular driving pattern from a *first destination 114.1* to a *second destination 114.2*, the *route computer system 48* records the a summary of the driving pattern in a *data structure 144* illustrated in *Fig. 9*, and records the details of the driving pattern in a *linked list data structure 146* illustrated in *Fig. 10*. More particularly, for each driving pattern, the *data structure 146* contains an index to the *first destination 114.1* with reference to the *data structure 134* of *Fig. 7d* in the field *Destination\_ID*, and the day of week and time of day when the trip was commenced in respective *DayOfWeek* and *TimeOfDay* fields. Upon reaching the *second destination 114.2*, the index of the *second destination 114.2* is recorded in the *NextDestination\_ID* field. The *Distance*, *Duration* and  $\square$  *Energy* fields contain the distance traveled between the *first 114.1* and *second 114.2 destinations*, the trip duration, and an estimate of the energy consumed therebetween, respectively, or average values thereof. As particular driving patterns are followed over time, the *route computer system 48* can determine associated statistics, so as to provide for values of associated *Likelihood* and *TimeOfDay\_Tolerance* fields of the associated record in the *data structure 144*. For example, over time a particular driving pattern may be used repetitively, such as driving from home to work in the morning,

or driving from work to home in the evening. The starting times of the corresponding repetitive trips would tend to cluster in a group that, for example, might be characterized by a normal distribution having a mean and standard deviation. Accordingly, the *TimeOfDay\_Tolerance* could, for example, be a value expressed in terms of the standard distribution of the group of clustered starting times. For the same day of week and time of day, there may be several different driving patterns that develop over time, in which case, different driving patterns will have different associated likelihoods, which are calculated over time by the *route computer system 48* and stored in the *Likelihood* field of the *data structure 144*.

[0051] The *Route\_ptr* field of the *data structure 144* of *Fig. 9* contains a pointer to the *linked list data structure 146* of *Fig. 10* containing the details of the driving pattern of the route traveled. The first record of the *linked list data structure 146* contains the index of the *first destination 114.1* which is stored as *Destination\_ID(1)* in the field *Destination\_ID*. If the *first destination 114.1* is associated with a particular *node 112* of a *road 108*, then the corresponding pointer *Road\_ptr* to that *road 108*, the index *Node\_ID* of that *node 112* and the associated *elevation 118* are also recorded in the corresponding

record of the *linked list data structure 146*. Furthermore, if the *node 112* is at an *intersection 110*, then the index *Intersection\_ID* of that *intersection 110* is also in the corresponding record of the *linked list data structure 146*. As the *vehicle 14* travels along the road or *roads 108*, these steps are repeated for each *node 112* or *destination 114* along the route, and the distance from the *first destination 114.1* and the energy consumed either since the *first destination 114.1* or since the previous *node 112* are recorded in the *distance* and *Energy* fields respectively. Upon reaching the *second destination 114.2*, the information in the *data structure 144* of next destinations illustrated in *Fig. 9* is updated, and using the route information from the *linked list data structure 146*, the *linked list data structures 142* of *Fig. 8d* are updated for each *intersection 110* and *road 108* along the route, so as to add the *first 114.1* and *second 114.2 destinations* and associated *destination circles 116* to the list of reachable destinations from those *intersections 110* along those *roads 108*. Accordingly, the *linked list data structure 142* of *Fig. 8d* contains indices for the *destinations 114* and *destination circles 116* that have been actually reached in accordance with the historical driving patterns of the *vehicle 14*. This information could also be tailored to particular *drivers 60.1*, so as to

provide for accommodating different driving patterns for different *drivers 60.1* of the same *vehicle 14*, thereby improving the accuracy of associated predictions of driving patterns during operation of the *vehicle 14*. Furthermore, upon reaching the next *destination 114* on a subsequent trip, the associated index of this *destination 114* is recorded in the *SubsequentDestination\_ID* field of the *data structure 144* of *Fig. 9*, so as to provide for future predictions of the next subsequent trip associated with the original *first destination 114.1*.

[0052] The data structures illustrated in *Figs. 5* through *10* can be used to retrieve a variety of useful information.

[0053] For example, given a measure of location, i.e. *latitude 104* and *longitude 102*, of the *vehicle 14* at a particular point in time, the corresponding pointer *RoadList\_ptr* from the *data structure 120* of *Fig. 5* can be used to find, from the *linked list data structure 124* of *Fig. 6a*, pointers *Road\_ptr* and associated ranges of indices *nodeID\_min* and *nodeID\_max* to the *linked list data structure 126* of *Fig. 6b*, whereby for the range of *nodes 112* between *nodeID\_min* and *nodeID\_max*, the *latitude 104* and *longitude 102* from the *linked list data structure 126* of *Fig. 6b* can be compared with the *latitude 104* and *longitude 102* of the *vehicle 14* from the *vehicle location sensor 42* to de-

termine the *road 108* and *node 112* thereof upon which and at which the *vehicle 14* is located.

[0054] As another example, given a measure of location, i.e. *latitude 104* and *longitude 102*, of the *vehicle 14* at a particular point in time, the corresponding pointer *DestinationCircle\_ptr* from the *data structure 120* of *Fig. 5* can be used to find, from the *linked list data structure 128* of *Fig. 7a*, indices *DestinationCircle\_ID* to the *data structure 130* of *Fig. 7b*, which provides, for each *destination circle 116*, a pointer *DestinationCircle\_ptr* to the *linked list data structure 132* of *Fig. 7c* containing a list of indices of the associated *destinations 114*, which can be searched to determine whether or not the *vehicle 14* is in general proximity to a particular *destination 114*. Furthermore, using the *data structure 134* of *Fig. 7d* which provides the *latitude 104* and *longitude 102* of each destination, or the *data structure 130* of *Fig. 7b* which provides the *latitude 104* and *longitude 102* of each *destination circle 116*, the *route computer system 48* can determine whether the *vehicle 14* is located at a particular *destination 114* or within a particular *destination circle 116*.

[0055] As yet another example, given a measure of location, i.e. *latitude 104* and *longitude 102*, of the *vehicle 14* at a particular point in time, the corresponding pointer *IntersectionList\_ptr*

from the *data structure 120* of *Fig. 5* can be used to find, from the *linked list data structure 136* of *Fig. 8a*, indices *Intersection\_ID* to the *data structure 138* of *Fig. 8b*, which provides, for each *intersection 110*, a pointer *DestinationReachableList\_ptr* to the *linked list data structure 142* of *Fig. 8d* containing a list of indices of the associated *destinations 114* and *destination circles 116* that are reachable from that *intersection 110*, which can be searched to determine whether or not the *vehicle 14* could be traveling to a particular *destination 114* or *destination circle 116*. If the *second destination 114.2* predicted by the *route computer system 48* is not part of a list of those reachable from the present location of the *vehicle 14*, then the predicted *second destination 114.2* would need to be revised by the *route computer system 48*. This operation can be further refined to consider only *destinations 114* that are reachable in the present direction of travel, by using the *linked list data structures 142* pointed to by the pointers *DestinationReachableList\_1\_ptr* or *DestinationReachableList\_2\_ptr* from the *linked list data structure 140* of *Fig. 8c* addressed by the pointer *IntersectionRoadList\_ptr* from the *data structure 138* of *Fig. 8b*, depending upon the *road 108* upon which *vehicle 14* is traveling and the direction of travel thereon.

[0056] Given the *energy management system 10* illustrated in *Figs.*

, and the example of associated data structures 120, 124–146 illustrated in Figs. 5 through 10, the operation of the *energy management system 10* will now be described with reference to the flow charts illustrated in Figs. 11 through 14.

[0057] Referring to Fig. 11, the *energy management system 10* commences an associated *energy management control process (1100)* with step (1102) by checking the state of the vehicle ignition key. If the vehicle ignition key is on, the location, i.e. *latitude 104* and *longitude 102* (and *elevation 118* if available), of the *vehicle 14* are determined in step (1104) from the *vehicle location sensor 42*, e.g. GPS system. When the vehicle ignition key is turned on, the *vehicle 14* will in most cases will be at a *destination 114*, in which case the time that has been accumulated since first arriving at that destination is calculated in step (1106). If the processes of steps (1102) through (1106) are not performed by the *route computer system 48*, then in step (1108), the location of the *vehicle 14* and the time accumulated at the current location are transmitted to the *route computer system 48*. In step (1110), travel of the *vehicle 14* is commenced on electric power from the *energy storage device 22*, e.g. *battery 22.1*, assuming that there is sufficient stored energy to do so, as



would typically be the case for a series hybrid electric vehicle. Then, the *route computer system 48* commences a *route responsive control process (1200)*, which is illustrated in *Fig. 12*.

[0058] Referring to *Fig. 12*, the *route responsive control process (1200)* commences with step (1202) wherein the *route computer system 48* establishes a hierarchy of likely *destination circles 116*, for example, by ranking the *Likelihood* values from the *data structure 144* of *Fig. 9*, for the *Destination\_ID* of the *destination 114* corresponding to the starting location of the *vehicle 14*, weighted according to or governed by the day of week and time of day in comparison with the associated *Day-Of-Week*, *TimeOfDay* and *TimeOfDay\_Tolerance* values from the *data structure 144*, which is learned by the *route computer system 48* from previous trips by the *vehicle 14*.

[0059] For example, for many *drivers 60.1*, the most likely destination might be the location of their home, followed by the driver's work location which would be relatively highly likely during normal work days and normal departure times. Various *destination circles 116* would also likely become predictable, depending upon the day of week and time of day. Although weekend driving patterns are likely to be more random, probable destinations will be learned and identified by the *route computer system 48*. Generally,

the *route computer system 48* continuously determines the next probable *destination 114* of the *vehicle 14*, which generally would be situation dependent.

[0060] As a highest probability default from any point of origin, the *route computer system 48* would typically provide for a default stored energy range corresponding to a predetermined travel distance. For example, if the default energy range is one mile, then the *power generator 16* would not start until that circle distance from the origin was achieved. This would prevent unnecessarily starting the *power generator 16* for short distance travel or simply moving the *vehicle 14* in a driveway or parking lot. Additionally, this stored energy range would serve to increase the probability of predicting a *destination 114* based on the particular route, day of week, date, time, etc after initiating a particular driving pattern. A greater stored energy range available provides for reducing the likelihood of requiring operation of the *power generator 16*. However, when the *power generator 16* is operated, it provides for relatively higher power, relatively more efficient generation of *electric power 27* to charge the *energy storage device 22* in a relatively short period of time, after which the *route computer system 48* can revert to driving on stored energy when the

*destination 114* becomes relatively highly predicted.

[0061] When the location of origination is a *destination 114* corresponding to the driver's home, the most likely *destinations 114* therefrom can be dependent upon the day of week and time of day. For example, for a typical work schedule of Monday through Friday with possible weekend work activity, the *vehicle 14* would typically be driven to a work *destination 114* in the morning within a particular window of time, and with a particular number of occupants. Other work schedules, e.g. night or swing-shift, would similarly have an associated substantially regular schedule. On non-work days, e.g. Saturday and Sunday, the *destinations 114* are likely to be less predictable, but over time, a recognizable set of driving patterns are likely to emerge to and from various *destinations 114*, and with various numbers of occupants. The associated *destination circles 116* would typically include shopping centers and business districts. The negative affect of infrequent, random stops, e.g. to obtain fuel or stop at a store, can be mitigated if these occur during periods of travel on stored energy. Accordingly, the *route computer system 48* can provide for travel using stored energy in areas for which there are likely to be unpredictable or randomly occurring stops.

[0062] When the location of origination is a *destination 114* corresponding to the driver's work location, the most likely *destinations 114* therefrom would be the driver's home if departing at the end of the regular work day. During lunchtime, there would be associated *destination circles 116* -- having an associated margin of error -- for restaurant venues, and return to work therefrom after lunch would be highly predicable. A trip to an airport is likely to involve a unique route that is recognizable, particularly towards the end of the trip when near the airport. The negative affect of infrequent, random stops, e.g. to obtain fuel or stop at a store, can be mitigated if these occur during periods of travel on stored energy. Accordingly, the *route computer system 48* can provide for travel using stored energy in areas for which there are likely to be unplanned stops.

[0063] When the location of origination is a *destination 114* corresponding to an airport, the most likely destinations therefrom would be the driver's home if during evening hours (after work) or weekends, or possibly the driver's work location if arrival at the *destination 114* would likely be during normal business hours, e.g. if departing from the airport during the morning of a typical business day. If the *desti-*

*nation 114* being driven to is an airport, e.g. from either "work" or "home", the driving pattern would normally be atypical, but over a recognizable driving pattern, and typically during morning or evening hours.

[0064] On holidays, regular holiday destinations and returns to the driver's home are often repeatable, even if they occur only seldom. The *data structure 144* of *Fig. 9* can be expanded to incorporate calendar and holiday information so as to improve the recognition of these associated driving patterns.

[0065] If the location of origination is an unknown *destination 114*, or if the *destination 114* to which the *vehicle 14* is being driven is unknown, then the *route computer system 48* would use a default control mode for which the state of charge of the *energy storage device 22* is maintained within tighter limits of a nominal state of charge than would necessarily be the case if the *destination 114* and corresponding driving pattern were known and predictable. On relatively long highway trips across the country or state outside the scope of normal driving patterns, the *route computer system 48* would typically only utilize GPS and road topography for energy management, and the *energy management system 10* would not be expected to provide substantial improve-

ments in overall energy efficiency because a substantial amount of the power is generated by the *power generator 16* running at relatively high power levels for which the corresponding efficiency is already relatively high.

[0066] The *route computer system 48* can adapt to traffic jam situations by not recording the associated stops as destinations. A GPS *vehicle location sensor 42* can provide location estimates within  $\pm 50$  feet, so that stops within the roadway of a recognized *road 108* can be discriminated from valid *destinations 114*, for which the vehicle would typically be pulled off the road, e.g. into a driveway or parking lot.

[0067] The *route computer system 48* can be adapted to provide for ignoring, or pruning from the associated database, *destinations 114* associated with relatively infrequent stops, particularly if the size of the associated data base becomes excessively voluminous. For example, *destinations 114* occurring less than a threshold percentage of time, e.g. 10 percent, could be ignored or pruned from the database. Alternately, the *route computer system 48* could be adapted so as to require a threshold number of occurrences of a particular *destination 114*, before that *destination 114* is activated for route processing.

[0068] The designations of "home", "work", "airport" or other sig-

nificant places that are *destinations 114* can be programmed into the *route computer system 48* by the *operator 60* using the *operator interface 62*. Furthermore, the *route computer system 48* could provide for entering different information, and learning different driving patterns, for different *operators 60*. The *route computer system 48* could also provide for the *operator 60* to reset the learned information when the *vehicle 14* is sold, so that new the driving patterns and *destinations 114* of the new driver, *drivers 60.1* or *operators 60* of the *vehicle 14* can be learned.

[0069] Following step (1202), in step (1204), if the *power generator 16* is not operating, and, if from step (1206), the state of charge (SOC) or amount of stored energy in the *energy storage device 22*, e.g. *battery 22.1*, is sufficient to reach the most likely *destination 114* or most likely *destinations 114* with the limits on the minimum amount of stored energy to maintain in the *energy storage device 22*, then, in step (1208), the *vehicle 14* continues the trip on stored energy from the *energy storage device 22*. Otherwise, from step (1206), if, in step (1210), the state of charge or amount of stored energy in the *energy storage device 22* is less than a threshold *SOC Limit*, then, in step (1212), the *power generator 16* is started so as to generate sufficient *electric power 27* to

continue operating the *vehicle 14*. The hierarchy of likely *destination circles 116* could be adapted so as to always include a pseudo-destination that is only a short distance from the *first destination 114.1* / point of origination if the amount of stored energy in the *energy storage device 22* is sufficient to reach this pseudo-destination, so as to prevent unnecessarily starting the *power generator 16* if the *vehicle 14* is simply being repositioned, or returns to the *first destination 114.1* unexpectedly after a short journey. The *route computer system 48* commences a *route processing process (1300)*, either after the *power generator 16* is started in step (1212), or if, from step (1210), the state of charge is greater than or equal to the threshold *SOC Limit*.

[0070] Referring to *Fig. 13*, the *route processing process (1300)* commences with step (1302), wherein the actually traveled route is compared with the stored route associated with the most likely *destination 114*. The stored routes are from previous trips using the same driving pattern for which the associated energy usage of the *vehicle 14* is either recorded from estimates of actual usage, or estimated from the associated topography of the roads associated with the driving pattern. Accordingly, this stored route can be referred to as an energy-mapped route. For example,



the stored route is recorded in the *linked list data structure 146* illustrated in *Fig. 10*. In step (1304), the *route computer system 48* determines the likelihood that the predicted destination is the actual destination, for example, using the information from the *data structures 138, 140, 142, 144* and *146* illustrated in *Figs. 8b, 8c, 8d, 9* and *10*, subject to the condition that the actual *destination 114* must always be reachable from the current location of the *vehicle 14*. Generally, the *route computer system 48* would accumulate over time a database of *destinations 114*, including the number of occurrences, and would collect associated data for each trip. This database can be used in a variety of ways. For example, simple probability can be used to determine the next *destination 114* from any repeatable origin of the *vehicle 14*; generally predictions of a next *destination 114* that are correlated with a particular origin, time and date or day of week tend to be more exact. Correlations that also account for fuel quantity, driver identification, vehicle weight (passengers), holidays, and the *road 108* being traveled all improve the accuracy of the predictions. The number of inputs to be considered would depend upon the cost and the desired level of accuracy. Typically, time, date, point of origin, the *road 108* being traveled, and the

number of times a *vehicle 14* has been at an origin/*destination 114* would be sufficient for beginning and in-route predictions of *destination 114*. A variety of techniques can be used for the estimation of a likelihood that the *vehicle 14* is traveling to a particular *destination 114* or along a particular route, including fuzzy logic, neural networks, or Bayesian inference. The confidence of a particular estimate of a *destination 114* or likely associated driving pattern can be improved by confirmation from the *operator 60* or *driver 60.1*, e.g. by aurally or visually querying as to the correctness of a particular determination by the *route computer system 48*, and receiving either a switch-activated response thereto, or a spoken response thereto which could be automatically detected using a speech recognition system.

[0071] If, in step (1306), the likelihood that the *vehicle 14* is traveling to a predicted destination is less than a threshold, e.g. 50 percent, then if, in step (1308), there are additional stored routes that lead to the most probable *destination 114*, then in step (1310), the next stored route is determined and the process repeats with step (1302). Otherwise, from step (1308), in step (1312), the *route computer system 48* sets a default control mode for the *power generator 16* and

*electrical power controller 18*, for example, load following by the *power generator 16* with limitations on the amount of energy stored in the *energy storage device 22*, e.g. so as to maintain a nominal state of charge of the *battery 22.1*.

Then, in step (1314), the *route computer system 48* records the route and energy usage of the *vehicle 14*, for example, in the *data structure 146* of *Fig. 10*, and in step (1316), the *route computer system 48* determines if the actual route either corresponds to a stored driving pattern leading to a stored *destination 114*, or can lead to a stored *destination 114*. If, in step (1318), the actual route corresponds to a stored driving pattern leading to a stored *destination 114*, or can lead to a stored *destination 114*, then, in step (1320), the *route computer system 48* determines the most likely stored destination corresponding to the actual route, after which the *route responsive control process (1200)* is restarted. Accordingly, the hierarchy of predicted *destinations 114* is continuously updated during the operation of the *vehicle 14*, wherein as vehicle distance and directional changes are accomplished, and possible destinations are eliminated, the predicted *destination 114* becomes more and more certain. Otherwise, from step (1318), in step (1322), the default control mode is continued, in step (1324) the

route information continues to be recorded, and, in step (1326), the *route processing process (1300)* returns to the step following the point of invocation, e.g. to step (1214) of the *route responsive control process (1200)*, as is described more fully hereinbelow.

[0072] If, in step (1306), the likelihood that the *vehicle 14* is traveling to a predicted destination is greater than or equal to the threshold, e.g. 50 percent, then, referring to *Fig. 14*, the *predicted route processing process (1400)* commences with step (1402), wherein the *route computer system 48* successively determines the next waypoint -- e.g. either a *node 112* of the *road 108*, an *intersection 110*, or a *destination 114* -- on the stored route to the predicted *destination 114*, for example, using the *linked list data structure 146* of *Fig. 10*. In step (1404), the control of the *power generator 16* and *energy storage device 22*, e.g. *battery 22.1*, are optimized, e.g. so as to minimize the amount of *fuel 28* required to reach the next waypoint or to reach the predicted *destination 114*, possibly subject to constraints on the amount of energy stored in the *energy storage device 22* upon reaching the predicted *destination 114*, by sharing the energy resources of the *energy storage device 22*, *power generator 16*, vehicle inertia and regenerative braking. Start/stop, low speed and low load

requirements would typically make maximum use of the *energy storage device 22* e.g. *battery 22.1*, for *electric power 27* to drive the *traction motor 20*. For example, with a *recuperated turbine engine 64* as the *power generator 16*, the *fuel 28* and an associated *recuperator 68* could be controlled. Generally, the *route computer system 48* continuously updates calculated energy requirements to travel the oncoming segment of the *road 108*. In step (1406), the *route computer system 48* determines the likelihood that the actual destination is within a *destination circle 116*, and then if, in step (1408), this likelihood exceeds a relatively high threshold, e.g. 90 percent, then, in step (1410), *route computer system 48* determines if the combination of recoverable stored energy -- e.g. the combination of the state of charge of a *battery 22.1* and the heat recovery potential from the *recuperator 68* of a *recuperated turbine engine 64* *power generator 16*, or power from regenerative braking -- is sufficient for the *vehicle 14* to reach the most likely *destination circle 116*. If not, but if, in step (1412), the likelihood of the actual destination being within a *destination circle 116* is greater than the relatively high threshold, e.g. 90 percent, then the process repeats with step (1402). Otherwise, from either step (1408) or step (1412), if the likelihood of the actual

*destination 114* being within a *destination circle 116* is less than or equal to the relatively high threshold, e.g. 90 per cent, then the *route processing process (1300)* is restarted.

[0073] From step (1410), if the combination of recoverable stored energy is sufficient for the *vehicle 14* to reach the most likely *destination circle 116*, and if, in step (1414), the range to the predicted destination is not less than a terminal control threshold, then the *predicted route processing process (1400)* repeats with step (1402). Otherwise, from step (1414), if, in step (1416), the subsequent trip can be predicted, and if, in step (1418), the state of charge of the *energy storage device 22* is not optimized for the subsequent trip, then, in step (1420), the state of charge of the *energy storage device 22* is either increased or decreased so as to approach an optimal condition for the subsequent trip.

[0074] Typical drive times, distances, energy use, etc. can be used in longer term energy prediction needs. For example, predictions of energy use for at least the next day's first trip can permit the end of day state of charge of the *energy storage device 22* to be less than a constant standard in order to preclude starting the *power generator 16*, or to more efficiently run the *power generator 16* during the subsequent trip. If the subsequent trip is predicted to be rela-

tively short, it would be beneficial to charge the *energy storage device 22*, e.g. *battery 22.1*, during periods of high efficiency during the existing (preceding) trip and perhaps allow the subsequent trip to be entirely completed on stored power. This combination decreases efficiency on the existing trip while minimizing, or eliminating fuel consumption on the subsequent trip, thereby providing for an overall reduction in fuel consumption. Conversely, if the subsequent trip is predicted to be relatively long, the existing (preceding) trip may have an opportunity to more efficiently recover heat energy while allowing the state of charge of the *energy storage device 22* to decrease to a level lower than might otherwise be allowed. The use of energy from the *energy storage device 22* -- resulting in an end of trip lower state of charge thereof -- possibly in combination with heat recovery, e.g. from a *recuperated turbine engine 64*, to power the *vehicle 14*, provides for more efficient storage and use of excess *electric power 27* generated by the *power generator 16* / *electric generator or alternator 26* and by regenerative braking. This combination maximizes fuel efficiency on the existing trip while providing for greater operational efficiency on the subsequent trip.

[0075] From step (1420), or otherwise, from either step (1416) or

step(1418) -- i.e. if either the subsequent trip cannot be predicted or the state of charge of the *energy storage device 22* is optimized -- in step (1422), the *power generator 16* is controlled to recover latent energy and the *energy storage device 22* is controlled so as to achieve a desirable state of charge thereof at the end of the trip. For example, for a *recuperated turbine engine 64 power generator 16*, the flow of *fuel 28* is tapered down so as to provide for recovering engine heat, including heat from the *recuperator 68*. The fuel step-down rate will be a function of remaining energy requirements to reach the *destination 114* using the *power generator 16/electric generator or alternator 26* to drive the *traction motor 20* and the need/capability of the *energy storage device 22*, e.g. *battery 22.1*, to accept more charge. Then, in step (1424), if the range to the destination is less than a terminal shutdown threshold, in step (1426), the *power generator 16* is shut down, i.e. the *fuel 28* is cut off, and, in step (1428), the *predicted route processing process (1400)* returns to the step following its point of invocation, e.g. to step (1326) of the *route processing process (1300)*, from which the *route processing process (1300)* would return to step (1214) of the *route responsive control process (1200)*.

[0076] Referring again to *Fig. 12*, either upon return to the *route*



*responsive control process (1200) from step (1326) of the route processing process (1300) -- e.g. upon return from step (1428) of the predicted route processing process (1400) -- or following step (1208), if, in step (1214), the destination 114 has been reached within a margin or error, and/or the vehicle is paced in park, then in step (1216) the associated route data for the trip is stored in the associated data structures 138, 140, 142, 144 and 146 illustrated in Figs. 8b, 8c, 8d, 9 and 10 respectively. The route computer system 48 can also be adapted to announce the destination 114 to the operator 60 via the operator interface 62, e.g. using the Text or A/V Description data from the data structure 134 of Fig. 7d, and possibly to query the operator 60 to verify if this information is correct, or to request information about the destination 114 if this is a new destination 114. If, in step (1218), the power generator 16 is operating, then, in step (1220), the power generator 16 is controlled so as to recover latent energy to the energy storage device 22, e.g. battery 22.1, without shutting off the power generator 16. For example, if the power generator 16 is a recuperated turbine engine 64, then the flow of fuel 28 is tapered down so as to transfer heat energy stored in the recuperator 68 into useful energy, e.g. electrical energy, in the energy storage device 22. Then, in step*

(1222), if the vehicle ignition key is turned off, then, in step(1224), the *fuel 28* is shut off to the *power generator 16*, and remaining recoverable latent energy is recovered to the *energy storage device 22* with the *power generator 16* off. For example, a *recuperated turbine engine 64* can continue to run strictly from the heat energy of the *recuperator 68* without additional *fuel 28*, thereby continuing to generate *shaft power 23* that is converted to *electrical power 27* by the *electric generator or alternator 26*, which is then used to charge the *energy storage device 22*. Following step (1224), the *energy management control process (1100)* is terminated in step (1226). Otherwise, from either step (1214) or step (1222), the *route responsive control process (1200)* is repeated, beginning with step (1202).

[0077] Generally, an optimized *energy management system 10* would consider the affect of parasitic vehicle loads and losses that are independent of engine operation, such as aerodynamic losses or friction, some of which are intrinsic to the vehicle, and some of which can depend upon external factors such as weather or road conditions. Excess power from the *power generator 16* or from regenerative braking can be used to charge the *energy storage device 22*, and a discharge of stored energy from *energy storage device 22* can

be used as the sole source of *electric power 27* under conditions when the *power generator 16* might be otherwise operating at idle or substantially under capacity. The *route computer system 48* regularly updates the predicted energy requirements of the *vehicle 14* that would be necessary to reach an expected *destination* or *destinations 114* associated with a particular driving pattern. In addition to the baseline topography, these energy requirements can account for ambient conditions, e.g. temperature, pressure, wind velocity and direction, and precipitation; the weight of the *vehicle 14*; the energy (BTU) content of the *fuel 28*; the quantity of *fuel 28* available; tire pressure, and etc. As the number of trips or the travel distance on the same road are accumulated over time, the *route computer system 48* can optimize the control of the *hybrid vehicle system 12* to compensate for the affect of other external factors such as traffic flow, or lack thereof during rush hour traffic, which may be anticipated, and responsive to which the *route computer system 48* can determine the best use of the total available energy stored in the *vehicle 14*, i.e. whether it is better to charge the *energy storage device 22*, e.g. *battery 22.1*, or to shut off the *power generator 16* so as to conserve *fuel 28*. For some trips, the *power generator 16* would not be

run at all, but instead, the *vehicle 14* would be run entirely from *electric power 27* from the *energy storage device 22* which would have been pre-charged by either the *power generator 16* running the *electric generator or alternator 26* in anticipation thereof during a previous trip, or by *electric power 27* from a *stationary electrical power source 54*. Unless the state of charge of the *energy storage device 22* were very low, the *energy management system 10* would typically not operate the *power generator 16* at the beginning of a trip, but instead would first determine the a predicted *destination 114* if possible, and not start the *power generator 16* until either necessary or desirable in association with a likely driving pattern associated with the predicted *destination 114*. The *power generator 16* would be necessary for load following if the *destination 114* cannot be predicted, or if the state of charge of the *energy storage device 22*, e.g. *battery 22.1*, is less than or equal to a minimum threshold. Knowledge of the predicted *destination 114* provides for conserving fuel and decreasing emissions from the *power generator 16* in a *hybrid vehicle system 12* with a *vehicle location sensor 42* by enabling the *power generator 16* to shut down in advance of reaching the predicted destination. Furthermore, for a *power generator 16* such as a *recuperated turbine engine 64*

from which latent heat can be transformed to useful power, the combination of heat recovery after shutdown of the *power generator 16* and/or more efficient energy generation during operation of the *power generator 16* in the seconds and minutes prior to reaching a predicted *destination 114* provides a fuel savings.

[0078] The *energy management system 10* can provide for reduced fuel consumption by shutting off the *power generator 16* and running on stored energy from the *energy storage device 22* during periods of relatively low to negative power demands by the *vehicle 14*, and by operating the *power generator 16* at relatively high efficiency -- typically with relatively high power output -- during periods when power is required from the *power generator 16*, and using excess power that may be generated by the *power generator 16* under these conditions to charge the *energy storage device 22*. For example, in the first segment of 1369 seconds of the Federal Test Procedure (FTP) used to evaluate vehicle fuel economy and emissions performance, i.e. the city cycle, 565 seconds are spent at zero or negative power, when a conventional engine power generator would otherwise be operating at idle fuel flow in a non-hybrid vehicle system -- at zero percent fuel efficiency. Under the same condi-

tions for a *hybrid vehicle system 12*, the *power generator 16* might not be operated at all, or might be operated at relatively high efficiency to generate power that is otherwise used to charge the *energy storage device 22*. The *energy management system 10* can provide for reduced emissions from a *power generator 16*, e.g. *prime mover 16'*, by reducing the number of starts thereof, e.g. by providing for operation over some driving patterns using only the *energy storage device 22* as a source of power; and by operating the *power generator 16* under conditions of relatively high efficiency for which the controls are optimized to reduce fuel consumption subject to constraints on emissions.

[0079] For example, once the *route computer system 48* determines a likely route of the *vehicle 14* for a particular trip, then the associated control schedule governing the operation of the *power generator 16* and *energy storage device 22* can be optimized in advance of the remainder of the trip, with advanced knowledge of the forthcoming requirements of the likely route, so as to account for topography of and distance along the *roads 108* on the expected route, and the expected driving speeds thereon, thereby providing for a global optimization of controls that account for both the overall driving cycle and the particular operating con-

dition at a given time, rather than merely the particular operating condition at any given time. Stated in another way, without advanced knowledge of the route, the control laws of the *power generator 16* and *energy storage device 22* would be limited to functions of current measurables, e.g. driver accelerator pedal demand, *battery 22.1* state of charge, and *power generator 16* operating conditions, e.g. operating speed and a measure of load, e.g. mass air flow or manifold absolute pressure. With advanced knowledge of the route, however, the control laws of the *power generator 16* and *energy storage device 22* can be also be expressed in terms of route dependent variables, such as distance along the route, so as to account for anticipated variations in elevation, anticipated changes in velocity, or anticipated stops at intersections. Furthermore, a control schedule that accounts for the particulars of a particular route can account for energy recovery from either regenerative braking; or from a *recuperator 68* of a *recuperated turbine engine 64* obtained by control of the *recuperated turbine engine 64* in advance of reaching a destination.

[0080] For example, a baseline exemplary *hybrid vehicle system 12* comprising an *internal combustion engine 78* and a *battery 22.1*, operated exclusively with the *power generator 16*, i.e.

without using the *battery 22.1* and without regenerative braking, was predicted to have a fuel economy of 37.9 miles per gallon (MPG) over the FTP city cycle. This same exemplary *hybrid vehicle system 12* operated with complete advanced knowledge of the driving cycle in advance of commencing the trip, but constrained to operate so that state of charge of the *battery 22.1* at the end of the trip is the same as at the beginning, was predicted to be controllable to achieve a corresponding fuel economy of 45.9 MPG, for example, by shutting off the *power generator 16* after about 600 seconds, and restarting the *power generator 16* at about 1240 seconds. Such a control schedule might normally be referred to as a "cycle beater", because it is tailored to a particular driving cycle, e.g. the FTP city cycle, but would not necessarily provide for satisfactory results when the *vehicle 14* is driven over other driving cycles. However, the *energy management system 10* of the instant invention provides for robustly anticipating a particular likely driving schedule associated with a particular driving pattern of the *vehicle 14* on a particular day at a particular time, and can be expected to anticipate different driving schedules for different driving patterns that may be associated with different days or times. Accord-



ingly, to the extent that the control schedule can be adapted for improved overall operating efficiency given this advanced knowledge, then the *energy management system 10* of the instant invention provides for a robust cycle-dependent optimization of associated control schedules.

[0081] For example, when the exemplary *hybrid vehicle system 12* is operated with load following, with an additional 1 Kilowatt used to charge the *energy storage device 22* while the *power generator 16* is operating, including during coastdown and stopped conditions, this provides for shutting off the *power generator 16* at 1270 seconds, and the associated fuel economy was predicted to be 40.4 MPG. When the exemplary *hybrid vehicle system 12* is operated with load following, with an additional 2.5 Kilowatt used to charge the *energy storage device 22* while the *power generator 16* is operating, including during coastdown and stopped conditions, this provides for shutting off the *power generator 16* at 1108 seconds, and the associated fuel economy was predicted to be 45.0 MPG. When the exemplary *hybrid vehicle system 12* is operated with load following, with an additional 6.7 Kilowatt used to charge the *energy storage device 22* while the *power generator 16* is operating, including during coastdown and stopped conditions, this provides for shutting

off the *power generator 16* at 790 seconds, and the associated fuel economy was predicted to be 42.4 MPG. When the exemplary *hybrid vehicle system 12* is operated with load following, with an additional 10.0 Kilowatt used to charge the *energy storage device 22* while the *power generator 16* is operating, including during coastdown and stopped conditions, this provides for shutting off the *power generator 16* at 611 seconds, and the associated fuel economy was predicted to be 42.0 MPG. It is beneficial to operate the *power generator 16* during relatively demanding (i.e. energy/power demanding) portions of a particular driving cycle, whether of a present trip or of the next anticipated trip. Accordingly, for the exemplary *hybrid vehicle system 12*, if the *route computer system 48* were to anticipate the FTP city cycle as a particular driving pattern, then the exemplary *hybrid vehicle system 12* would be operated with load following, with an additional 2.5 Kilowatt used to charge the *energy storage device 22* while the *power generator 16* is operating, including during coastdown and stopped conditions, so as to provide for shutting off the *power generator 16* at 1108 seconds, which provides a fuel economy of 45.0 MPG. Upon commencing the next trip, the *hybrid vehicle system 12* would, for example, initially operate from either the *battery*

22.1 or the *power generator 16* until the associated driving pattern could be anticipated, and if so, would then operate in accordance with control schedules that are optimized for the driving pattern associated with that next trip, e.g. by operating the *power generator 16* during periods of relatively substantial load demand, during coastdown or stopped conditions to store energy in the *energy storage device 22* so as to provide for shutting off the *power generator 16* in advance of reaching an associated *destination 114*, in a manner that provides for recovering latent energy therefrom.

[0082] It should be noted that whether or not excess power generated by the *power generator 16* can be stored by the *energy storage device 22* generally depends upon the timing of excess power generation. For example, if the state of charge of a *battery 22.1* *energy storage device 22* is too high, then the *battery 22.1* may not be able to receive the additional charge that would be necessary to store all of the associated excess power. Accordingly, in order to avoid otherwise degrading overall system efficiency, the excess power would need to be timed so as to be provided when the *battery 22.1* can receive all of the associated charge. If the *battery 22.1* were at a relatively low state of charge,

then a considerable amount of excess power could be beneficial because the battery could then accept and store the associated charge, consistent with battery design guidelines. Otherwise, if the *battery 22.1* were at a relatively high state of charge, then a considerable amount of excess power would generally not be beneficial because some or all of the associated charge could not be stored by the *battery 22.1*, and the associated excess power would otherwise be wasted.

[0083] Energy recovered by regenerative braking would be expected to increase the fuel economy of the exemplary *hybrid vehicle system 12* by about 7 MPG from 45 MPG to 52 MPG for the FTP city cycle.

[0084] Generally, once a driving pattern becomes anticipated, so as to provide route information such as illustrated in the *linked list data structure 146* of *Fig. 10*, then the associated control schedule for controlling the *power generator 16* and the *energy storage device 22* can be determined, either from functions or tables that are predetermined using off-line optimization, or determined using on-line optimization over time from one occurrence of a driving pattern to another, using one or more known optimization techniques, e.g. linear programming, non-linear programming, or dy-

namic programming. For example, the same techniques that have been used to develop "cycle beater" control strategies can be used to determine optimized or quasi-optimized control schedules that are used by the *energy management system 10*.

[0085] While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

[0086] *I Claim:*